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REPORT

The subjective effects of random bit errors in *YUV* component video signals

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Research Department, Engineering Division
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Summary

This Report describes two sets of subjective test measurements of error visibility on pictures derived from digital YUV video signals sampled in compliance with CCIR Recommendation 601. The first set of tests measured the subjective picture impairment resulting from random, single-bit errors in either the luminance (Y) or chrominance (U/V) channels. The second set of tests measured the impairment in chroma-key performance produced by errors in the U or V components.

The results show that one random single bit error per second in the most significant bit (MSB) of the Y channel is just perceptible, and 10 per second in the MSB of the U/V channel. In the chroma-key tests, errors in the MSB of both U and V were just perceptible at 3 per second, and in addition, errors in the lower bit significances of the U channel were more visible than the V channel.

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THE SUBJECTIVE EFFECTS OF RANDOM BIT ERRORS IN *YUV* COMPONENT VIDEO SIGNALS

K.R. Slavin, B.Sc.

1. Introduction

When a digital signal is transmitted through a communications link, it may be subject to impairment caused by bit errors. These errors can occur either singly or grouped in bursts. Single bit errors can occur in a transmission link which is subject to noise or inter-symbol interference.

This Report describes results of investigations into the subjective effects of single random bit errors in a digital *YUV* signal. The investigation was aimed at establishing criteria for the limits of acceptable link performance.

In contrast, bursts of errors may result from effects such as tape-recording drop-out, timing jitter, electrical interference, de-scrambling extension or error correction failure. Investigation of the subjective effects of such burst errors will be the subject of later work.

The *YUV* video signal used in the investigation was sampled in compliance with CCIR Recommendation 601. Line and field synchronisation information was not sent via the error insertion system, so avoiding any equipment-dependent behaviour associated with any particular method of recovering this information from the link. Therefore, in practice, the results obtained may have to be downgraded if the picture synchronisation is affected by bit errors.

2. Direct effects of errors in Y and U/V signals

2.1. Experimental details

Fig. 1 is a block diagram of the equipment used. The digital *YUV* signal was obtained by sampling the red, green and blue video component signals at the line-locked frequency of 13.5 MHz, and quantising to 8 bits resolution per sample. These signals were then digitally matrixed to give Y, U and V, each sampled at 13.5 MHz. The U and V signals were then digitally filtered to half the bandwidth and sub-sampled to half the sample rate. For the Y signal, the codes 16 and 240 represented black and peak white with a coding range of ± 112 levels. The equipment used in the tests was constructed before coding level standards were agreed and therefore the luminance coding range was very slightly non-standard. In the standard coding range for luminance, peak white is represented by level 235. This small difference is estimated to cause a reduction in the measured impairment corresponding at most to 0.1 grade which is small compared to the standard deviation.

The *YUV* signal comprised two, 8-bit parallel data streams, one stream being the Y component and the other being the sample-interleaved U and V components. The error generator unit was able to selectively insert randomly timed, single-bit errors into any significance of bit in either data stream, and was able to generate up to 10^4 error events per second. The digital *YUV* signals were then converted back to analogue *RGB* form using filters defined in Reference 1. The resulting signals were displayed using a high-quality

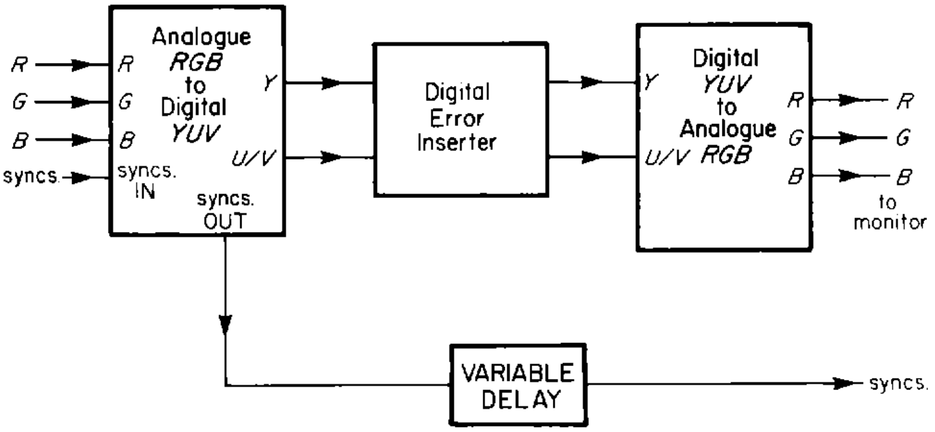

Fig. 1
Schematic of arrangement for the subjective assessment of direct YUV errors.

colour monitor in standard viewing conditions[2]. Errors in the luminance or colour difference signals could give rise to *R*,*G* and *B* values less than zero or greater than full saturation. Limiting was therefore required to prevent the arithmetic of the *YUV*-to-*RGB* matrix overflowing, which could cause very visible error effects.

2.2. Test procedure

The EBU 'Boats' and 'Blackboard' pictures were shown alternately throughout each subjective test session. Each test condition was viewed for 20 seconds followed by a 10-second rest interval during which the signals to the monitors were switched off. The pictures were graded according to the discrete values of the CCIR 5-point Impairment Scale given below:

CCIR 5-point Impairment Scale:

5 Imperceptible
4 Perceptible but not annoying
3 Slightly annoying
2 Annoying
1 Very annoying

Each test condition presented a specific error rate at a particular bit significance in either the *Y* or *U*/*V* channel. The conditions were ordered randomly and programmed into the error generator to be 'replayed' for the tests. 48 test conditions were assessed at each test session, of which 30 conditions occurred once only and the other 18 consisted of 9 pairs of identical conditions to be used as cross-checks for judging consistency in each observer.

A total of 24 observers took part in four separate test sessions lasting for twenty-four minutes each. The observers were seated at either 4– or 6–times picture height from the monitor.

2.3. Results

Figs. 2a and 2b give the mean impairment grades for errors inserted in the *Y* and *U*/*V* channels respectively with results for the 'Boats' and 'Blackboard' slides shown separately. The grade assessments were spread with an average standard deviation of about 0.6 of a grade. Much of this deviation is probably due to the impairment being assessed with integer values of 1–5; it is thought that the figure would have been reduced by the use of a continuous rather than a discrete grading scale.

Of the 24 people who took part in the tests, three sets of results were rejected on the grounds of inconsistency. The remaining 21 sets of results were used which gives a standard error for the mean of about grade 0.15 for each result.

These results show that error visibility decreases very rapidly with bit significance. Errors in the MSB (and to a lesser extent the MSB-1) of the *Y* component of the 'blackboard' picture tended to be particularly visible as white dots on the blackboard area.

The results for grade 4.5 impairment (errors just perceptible by about half the observers) are summarised in Table 1 which gives figures for events/second and the corresponding bit-error-ratios.

In order to be able to compare relative error visibilities in video signals which may have different bit rates, it is considered that 'error-events-per-second' is a more appropriate measure for describing the error rate than 'bit-error-ratio'. However, even this description of error rate is not ideal. Error visibility is a function of the energy in an error, so the visibility will depend not only on the error amplitude but also on the error width, which is related to the number of pixels per line. Therefore, the visibility of errors in a given bit significance and at a given number of error-events-per-second will still depend to some extent on the video data rate.

As the data rate in these measurements for each of the *Y* and *U*/*V* channels is 108 Mbit/s or approximately 10^8 bits per second, it follows that an error rate of N events per second in a channel is the same as a bit-error-ratio of about $N/10^8$ for that channel.

The results are quoted in terms of error-events-per-second occurring in the *Y* (or *U*/*V*) data stream which includes data corresponding to the blanking intervals. The number of 'displayed' error-events-per-second occurring during the active picture is approximately 0.75 of the numbers given. If then, for example, the blanking intervals have been removed for transmission, errors in the MSB of the *Y* signal will be just perceptible at 0.75 error-events-per-second rather than 1.0 error-events-per-second (but still at a bit-error-ratio of 10^{-8}).

For errors in the most significant bits at rates which are at the threshold of visibility, the decision as to whether the errors are just perceptible or not will depend on the time taken to view the picture. For these tests the viewing time was 20 seconds. It is possible to make an estimate of how the assessment would change if the viewing time were varied.

Let p_1 = probability/second of an error occurring
and p_2 = probability of seeing an individual error

Then $p_1 p_2$ = probability of seeing an error in any one second

The probability of seeing an error in a time T is then given by $p(T) = 1 - (1 - p_1 p_2)^T$

For example, at the threshold of visibility errors in the MSB of the *Y* channel were just perceptible to half the viewers (i.e. $p(T) = 0.5$)

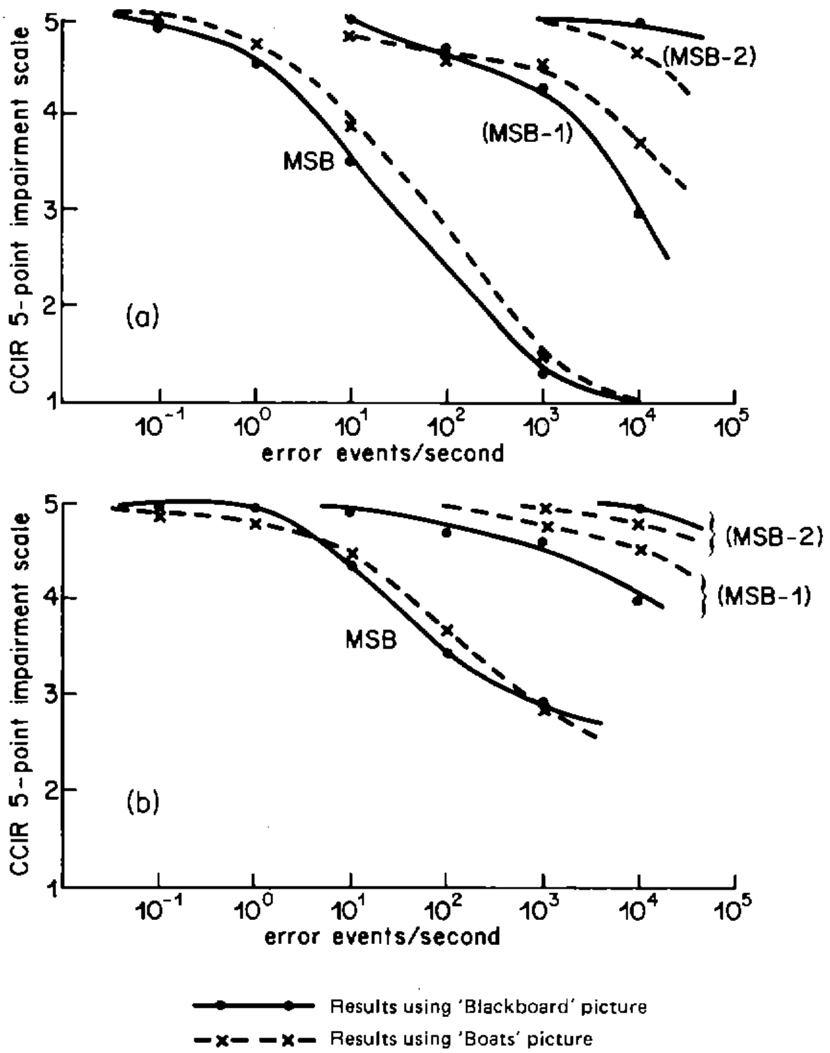

Fig. 2 — Error visibility for errors in bits of various significance.

a) Average impairment grade for errors in the *Y* signal

b) Average impairment grade for errors in the *U/V* signal

TABLE 1

Error rates for grade 4.5 on the impairment scale

Component	Bit Significance	Just Perceptible Events/second	 Bit-error-ratio
Y	MSB	1	10^{-8}
Y	MSB-1	100	10^{-6}
Y	MSB-2 to MSB-7	$> 10^4$	$> 10^{-4}$
U/V	MSB	10	10^{-7}
U/V	MSB-1	10^3	10^{-5}
U/V	MSB-2 to MSB-7	$> 10^4$	$> 10^{-4}$

in a 20 second viewing time. This gives a value for $p_1 p_2$ equal to 0.034. Thus, if the viewing time were increased to around 87 seconds, according to the above equation the errors would be perceptible to 95% of the observers giving a grade of 4.0 rather than 4.5.

Errors in the less significant bits are only visible at comparatively high error rates. The impairment is then more like that from random noise and the assessment is not particularly dependent on the viewing time.

3. Effects of errors on 'downstream' chroma-key

3.1. The effect of errors in chroma-keying signal

The previous results show that the direct effects of errors in the *Y* component are more visible than errors in the *U/V* components. However, if a signal containing *U/V* (chrominance) errors is processed by chroma-key equipment, the effects of errors may be more visible. Accordingly, measurements were made to assess the sensitivity of a typically instrumented chroma-key process to chrominance errors.

In chroma-key, two pictures, a 'foreground' picture and a 'background' picture are combined. Basically the foreground picture is processed to obtain a 'key' signal which controls the switching or mixing of the two pictures. The foreground picture is suppressed relative to the background for a range of colours (usually around blue) in the foreground scene. Fig. 3 shows a typical chroma-key colour range.

Chrominance (*U/V*) errors in the foreground signal will cause unwanted chroma-key switching if, as a consequence, the foreground colour crosses the chroma-key decision boundary.

Luminance (*Y*) errors in the foreground signal should not effect chroma-key although this may depend on the adjustment of processing equipment.

Errors in the background signal will not effect the switching key and will in any case, only be visible in areas of the output picture where the background signal is keyed in.

3.2. Experimental details

Fig. 4 is a block diagram of the equipment used.

As for the previous tests, analogue *RGB* signals were converted to digital *YUV* into which errors were inserted. The error generator was reconfigured so that errors could be injected independently into either the *U* or *V* components. The digital *YUV* signal was then reconverted to analogue *RGB* which was used as the foreground input to an 'Ultimatte 4' chroma-key unit.[3] A Philips *RGB* test-card generator was used for the background picture. The foreground picture was a critical chroma-key test slide containing a comb, a wig, a glass and some coloured spheres against a blue background. The background formed approximately 60% of the picture. Because of the time required to adjust the chroma-key set-up for each picture, it was not possible to carry out measurements for a range of picture combinations during the tests. However, with the picture

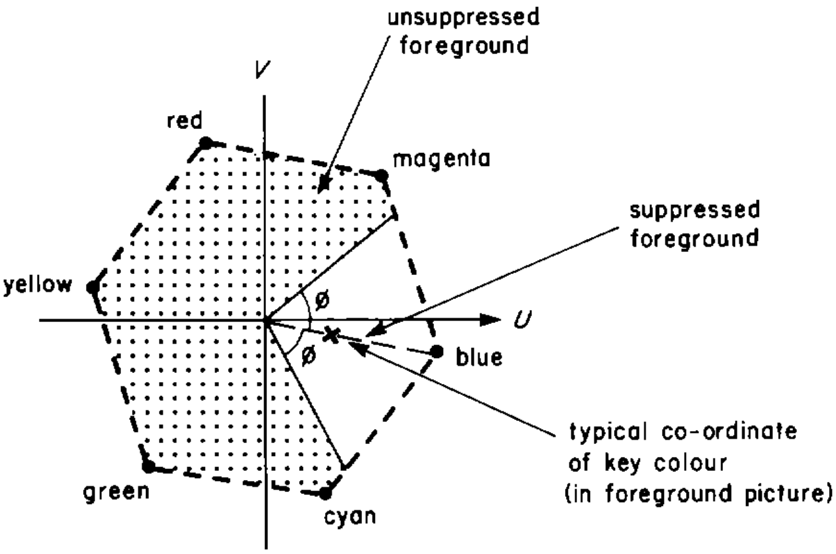

Fig. 3 — Chroma-key operation: diagram showing range of colours over which foreground suppression occurs.

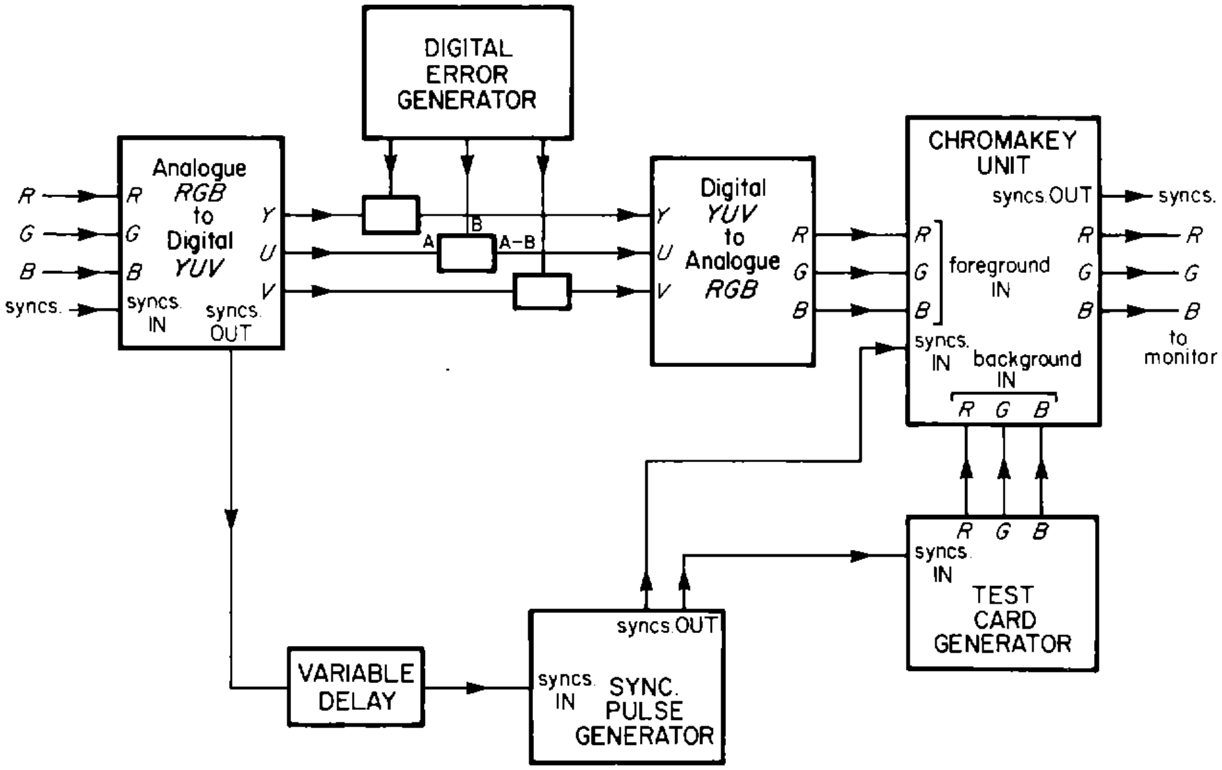

Fig. 4 – Schematic of arrangement for the subjective assessment of error impairments with downstream chroma-key.

combination chosen, the error events were more than usually visible, so the test results tend towards 'worst case'.

In initial tests it was found that, with errors in the *U* component, errors in the MSB-2 tended to be more visible than errors in the MSB-1. This was because it so happened that the blue key-colour in the foreground picture had, for the most part, a particular binary value for the *U* component such that an error in the MSB-1 moved it to the right in *U/V* space (i.e. further into the keying area shown in Fig. 3) whereas an error in the MSB-2 moved it to the left and out of the keying area, causing unwanted switching back to the foreground picture.

These visibility effects could have been quite different if the blue key-colour of the foreground had had a *U* component with a different binary value. It was decided, therefore, to obtain worst-case error-visibility measurements for each significance of bit. The error insertion system for the *U* component was accordingly reconfigured so that instead of logically inverting a bit of a particular significance, an error of the same magnitude was arithmetically subtracted from the *U* value; i.e. the *U/V* coordinate was always moved to the left in Fig. 3 by the error event.

This phenomenon in the error visibility was not evident for errors in the *V* component because the blue of the foreground had predominantly a near zero or small *V* component value. In this case as can be seen from Fig. 3, an error causing a vertical shift in the *U/V* coordinate in either direction can take the coordinate outside the area of foreground suppression. Therefore, errors in the *V* component were inserted in the more conventional fashion by logical bit inversion.

3.3. Results

The results of this second set of subjective tests are shown in Figs. 5a and 5b for errors in the *U* and *V* components respectively. The error rates for which errors were just visible to about half the observers (i.e. grade 4.5) are given in Table 2.

The data-rate for each of the *U* and *V* components is 54 x 10^6 bit/s. Each table entry may be divided by this value to obtain bit-error-ratios.

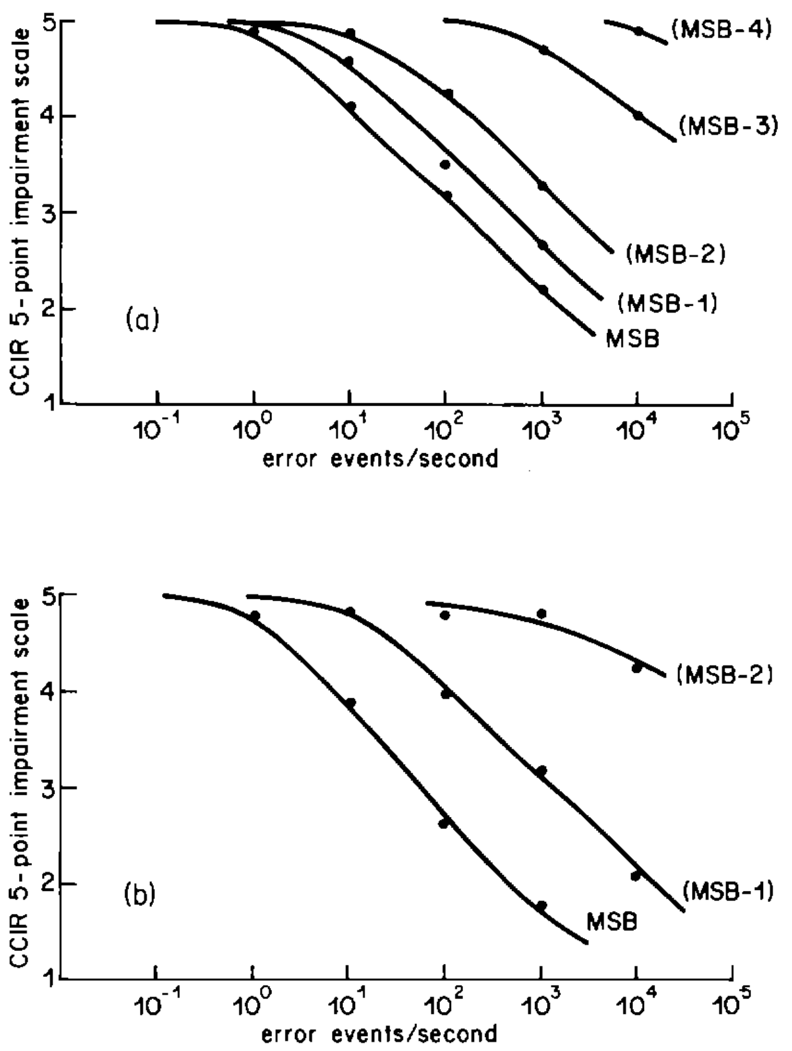

Fig. 5
Error visibility with chroma-key processing.

a) Average impairment grade for errors of various magnitudes in the *U* component

b) Average impairment grade for errors in various bit significances in the *V* component.

The relative sensitivity of chroma-key to errors in the *U* and *V* components depends on the key colour and on the keying angle (ϕ) of the area for foreground suppression (Fig. 3). The keying colour determines the orientation of the suppressed foreground area. With the blue keying colour (i.e. close to the *U* axis), the effect of errors in the *V* signal is increased as the keying angle is reduced. However, values for the keying angle were not ascertainable from the controls of the Ultimatte equipment and it was therefore not possible to assess the effect of changing this angle on error susceptibility. Comparison of Tables 1 and 2 shows that the process of chroma-key makes chrominance errors much more visible. The difference in visibility is particularly pronounced for errors in bits of lower significance in areas of the picture where they cause a switch from the background picture to the blue of the foreground picture.

TABLE 2

Error-events-per-second for grade 4.5 on the impairment scale

Channel	MSB	MSB-1	MSB-2	MSB-3	MSB-4 to MSB-7
U	3	10	30	2×10^3	$>10^4$
V	2	30	3×10^3	$>10^4$	$>10^4$

4. Comparison of error visibility in digital PAL and *YUV*

Comparisons can be made between the results for *YUV* components and earlier error measurements made with composite PAL signals sampled at three times colour sub-carrier frequency and quantised to 8-bit resolution[4,5]. The PAL results, however, were obtained by inserting random errors into a *serial* bit stream and are therefore not presented in the same manner, i.e. not giving the visibility of errors in the different bit significances.

The PAL measurements showed that the error visibility was the same for the picture displayed either in colour or in monochrome. This is consistent with the *YUV* results which show that luminance errors are significantly more visible than chrominance errors.

Comparing the results for monochrome PAL and *Y* is complicated by the fact that the coding ranges are different. In the PAL case the luminance signal occupies only about 140 of the 256 quantising levels available because of allowance for synchronising pulses and chrominance headroom. Consequently an error in the MSB corresponds to 91% of the full range luminance signal for a PAL signal but only 57% of the full range *Y* signal.

Bearing these points in mind, it was found that for PAL signals sampled at about 13.3 MHz with 8-bit resolution, the errors were perceptible by half the observers (i.e. grade 4.5) for a bit-error-ratio of about 10^{-7}. This corresponds to a threshold of perceptibility of 1.3 error-events-per-second at each significance of bit. If it is assumed that, like *YUV*, errors in the MSB are far more visible than in any other bit significance, then this result can be regarded as entirely due to errors seen in the MSB. This value of 1.3 is very close to the value of 1 per second for the *YUV* luminance channel MSB given in Table 1.

5. Conclusions

The impairments caused by bit errors in *YUV* component signals coded in accordance with CCIR Recommendation 601 have been assessed in a series of subjective tests. The results summarised in Table 1 show that errors in the luminance channel were more visible than errors in the chrominance channel. Errors in the MSB of the luminance channel were just visible at an event rate of one per second and errors in the MSB of the chrominance channel were just visible at 10 error events per second. In addition, error visibility decreased very rapidly as a function of decreasing bit significance. For example, errors in bits of significance MSB-2 or lower were not visible, even at error rates as high as 10^4 events per second.

These results are broadly comparable with those obtained with PAL coded signals.

A second series of subjective tests measured the visibility of *U* or *V* errors with chroma-key processing. These tests, summarised in Table 2, showed that the processed picture was about three times more sensitive to such errors compared with the direct effects of chrominance errors. Errors in the output picture were just perceptible at only 2 or 3 error events per second in the MSB of the *U* or *V* components. In addition, the effects of low bit-significance errors in the *U* channel could be seen. For example, for the MSB-3 of the *U* channel, errors were just perceptible at a rate of 2×10^3 error events per second.

The general conclusion is that since the subjective impairment due to errors is increased by downstream processing such as chroma-key, these processes should set the standards for the acceptable error rates in *YUV* PCM transmission and recording systems. Further work is planned to investigate the effects of burst errors and of error concealment.

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